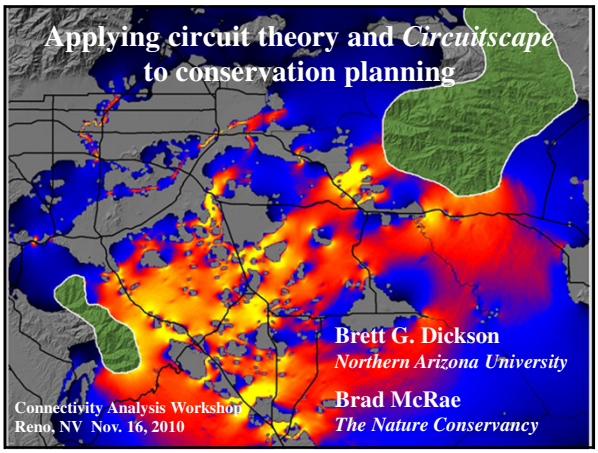
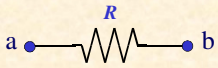


Making connectivity models work for conservation planning

- -Circuit theory intro
- -New methods:
  - -Least-cost/circuit 'hybrids'
  - -Detecting restoration opportunities
- -Example applications

Circuit theory foundations

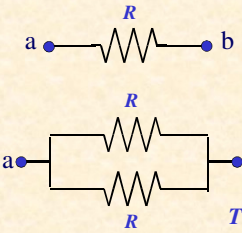
A simple circuit



R = Resistance

Circuit theory foundations

A simple circuit



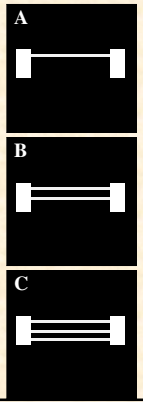
R = Resistance

$\hat{R} = R/2$

= Effective resistance

The resistance to current flow between two nodes separated by a network of resistors.

Effective resistance across landscapes



$\hat{R}$

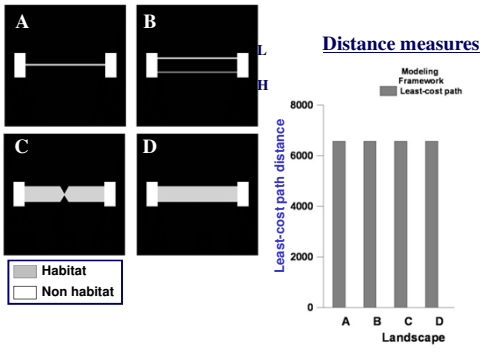
$\hat{R}/2$

$\hat{R}/3$

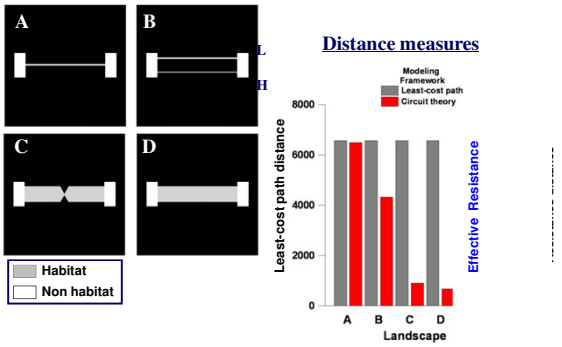
Distance measure with property of *decreasing* as more connections are added

- Incorporates multiple pathways
- Measure of *redundancy*

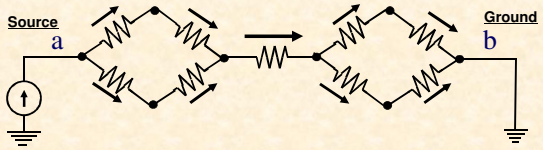
Simple landscapes (1000 x 1000 cells)



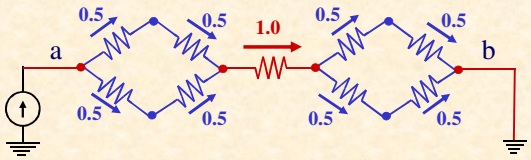
Simple landscapes (1000 x 1000 cells)



Current flow and connectivity mapping



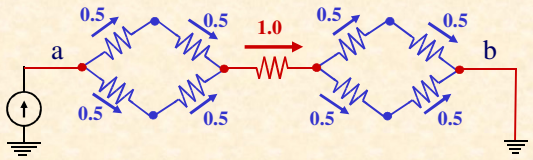
Current flow and connectivity mapping

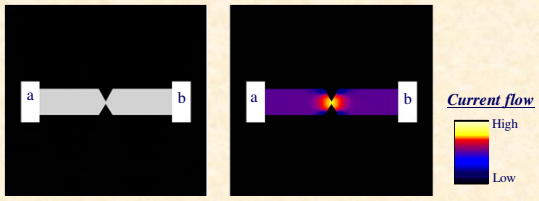


Current gives net passage probabilities of random walkers

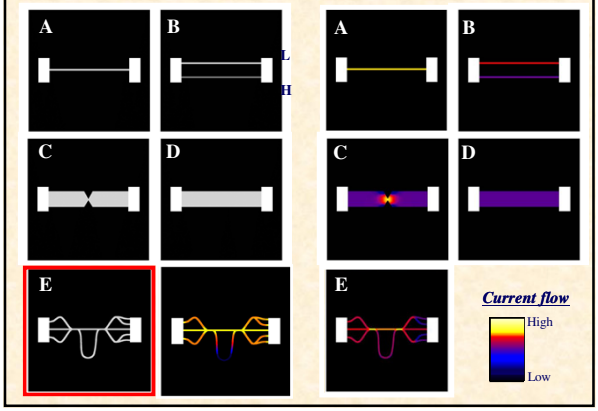
- Current densities

Current flow and connectivity mapping



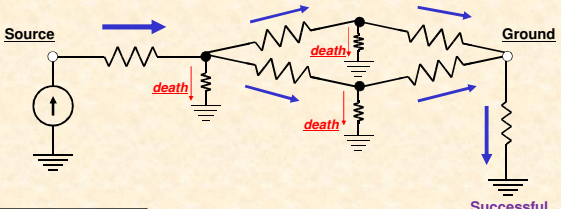


Simple landscapes (1000 x 1000 cells)



Current flow and connectivity mapping

- Describes flow of random walkers across a network of resistors, or "habitat" grid cells



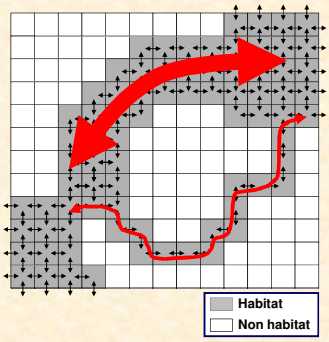
Permits link to probabilistic interpretation of animal movement and dispersal success across a "landscape network"

Using circuit theory to model connectivity

Random walkers on a landscape network grid of resistors, or a "resistance surface" (or conductance, permeability)

Greater connectivity if patches or "reserves" connected by:

- Wider rather than narrower pathways
- Multiple pathways
- More "permeable" habitat cells, i.e., those that provide lower resistance

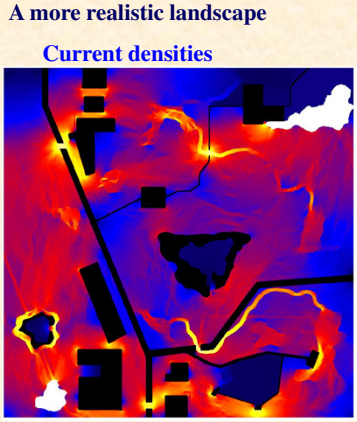


A more realistic landscape (1000 x 1000, 1-m cells)

- Resistance surface, where *R* ranges from 0 to infinity

A more realistic landscape

Current densities

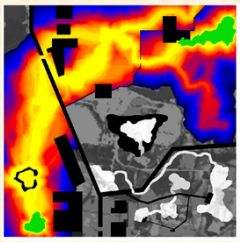


Current flow
High
Low

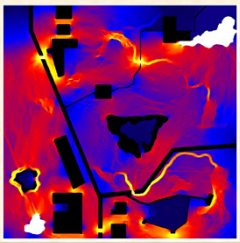
A more realistic landscape

Current flow
High
Low

Least-cost corridor:



Circuit theory:



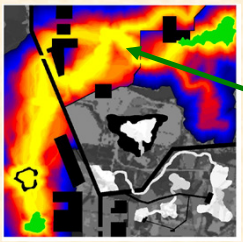
Making connectivity models work for conservation planning

- -Circuit theory intro
- -New methods:
  - -Least-cost/circuit 'hybrids'
  - -Detecting restoration opportunities
- -Example applications

Hybrid: constraining current to least-cost corridors

Current flow
High
Low

Least-cost corridor:



Constrain circuit analyses to low-cost routes

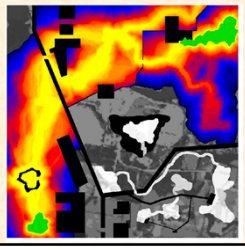
Hybrid: constraining current to least-cost corridors

Current flow

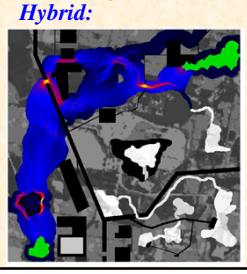
High

Low

Least-cost corridor:



Hybrid:

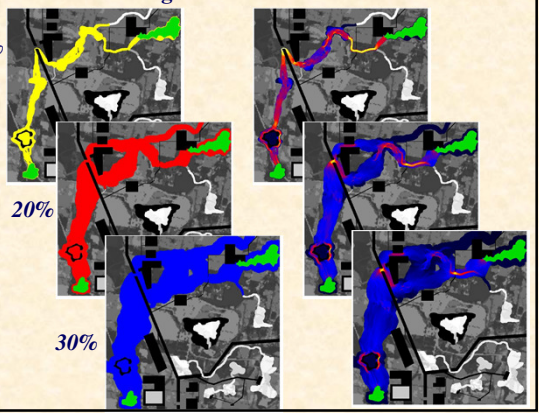


Hybrid: constraining current to least-cost corridors

10%

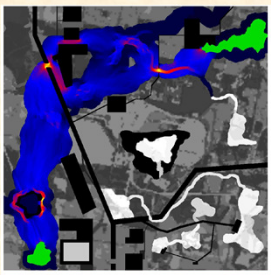
20%

30%

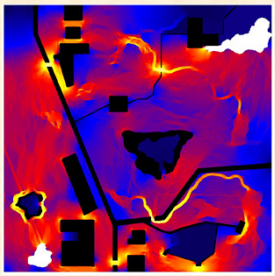


Hybrid: constraining current to least-cost corridors

Hybrid:

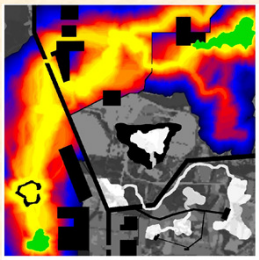


Entire region:



New method: Using circuit theory and **voltage gradients** to detect **restoration opportunities** (e.g., using least-cost corridors)

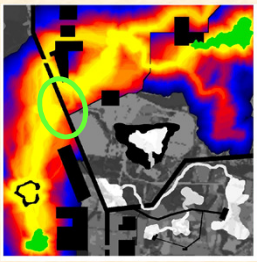
Corridor under present conditions:



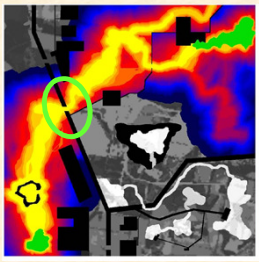
Restoration opportunities:

New method: Using circuit theory and **voltage gradients** to detect **restoration opportunities** (e.g., using least-cost corridors)

Old:



With restoration:



Making connectivity models work for conservation planning

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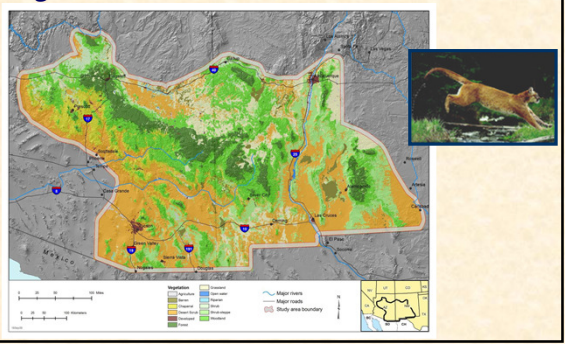
Planning for pumas in AZ and NM

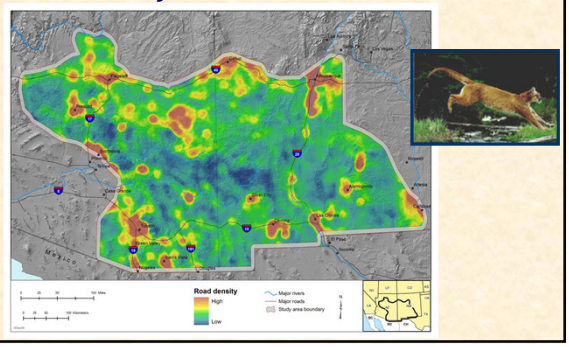
With Gary Roemer, Jill Rundall, and Kurt Menke

Vegetation *(expert-based weighting and ranking)*



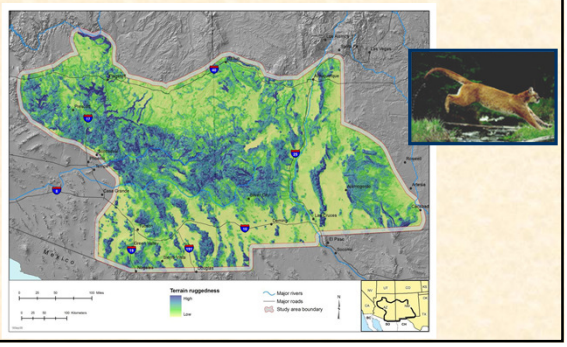
Planning for pumas in AZ and NM

Road density



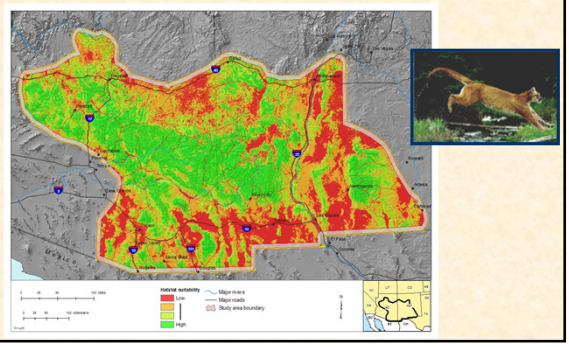
Planning for pumas in AZ and NM

Terrain ruggedness



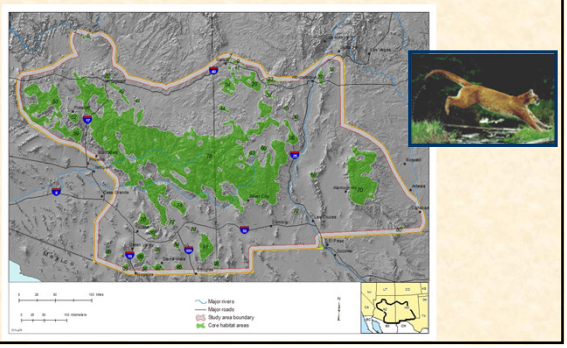
Planning for pumas in AZ and NM

Habitat quality



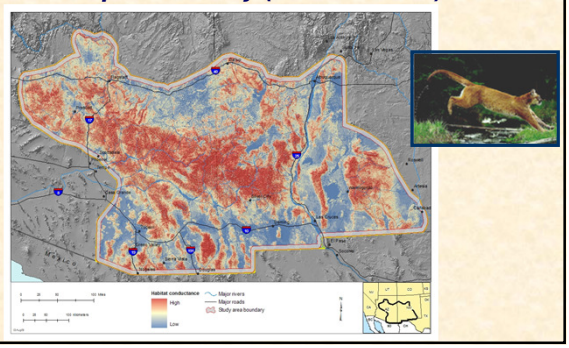
Planning for pumas in AZ and NM

Core areas



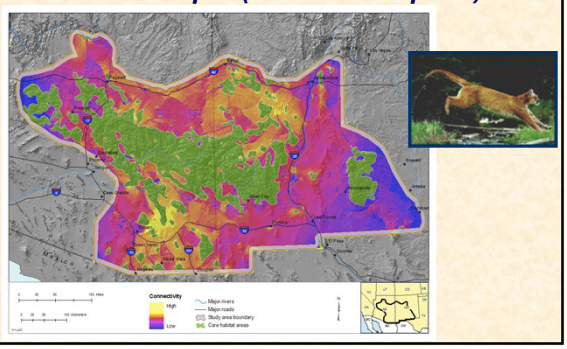
Planning for pumas in AZ and NM

Habitat permeability (conductance)



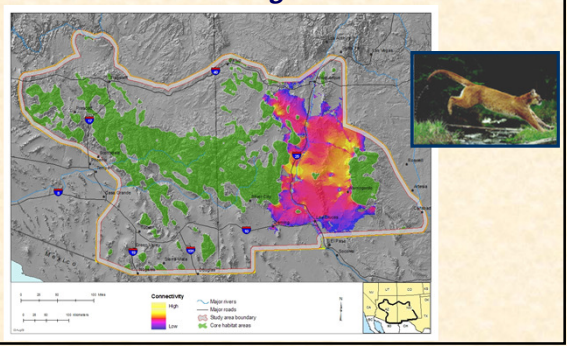
Planning for pumas in AZ and NM

Cumulative output (all core area pairs)

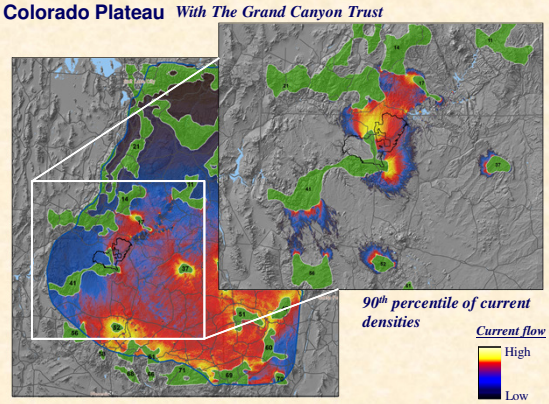


Planning for pumas in AZ and NM

Sacramento Mts - Mogollon Rim



Planning for multispecies connectivity on the Colorado Plateau *With The Grand Canyon Trust*



90th percentile of current densities

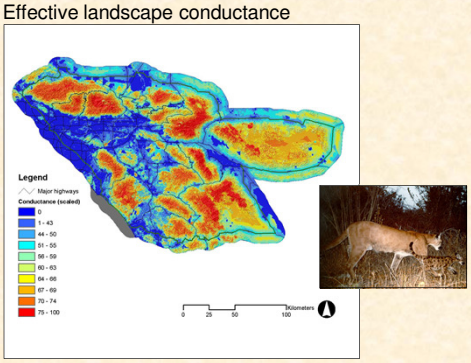
Current flow

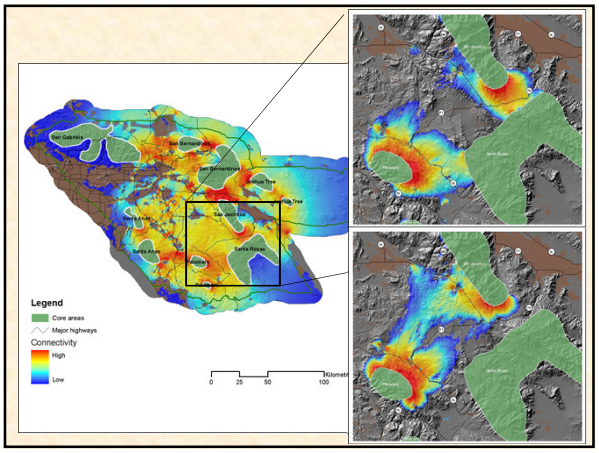
High

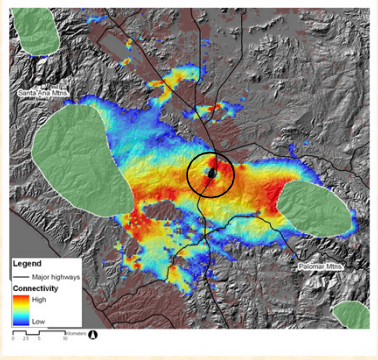
Low

Scenario modeling (puma in southern CA)

Effective landscape conductance



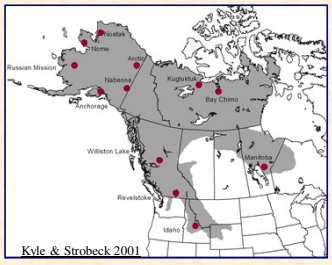




Population genetic applications

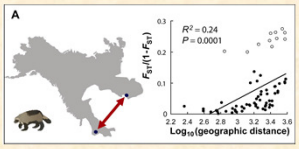
Good results with:

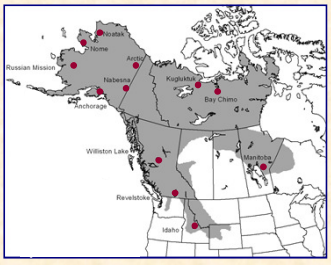
- Puma
- Sage-grouse
- Mahogany
- Wood frogs
- **Wolverines**



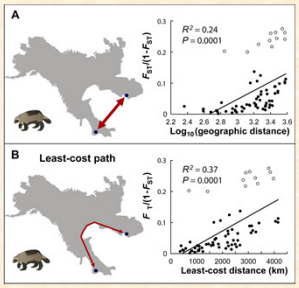
Kyle & Strobeck 2001

Population genetic applications



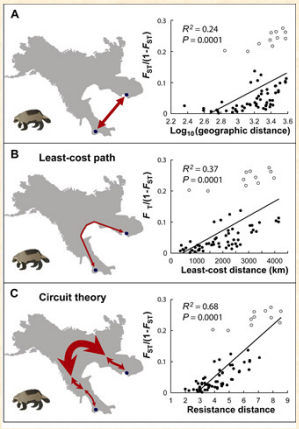


Population genetic applications



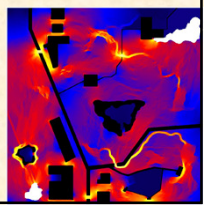
Population genetic applications

188% improvement in R^2



Take-home points

- ***Connectivity is not just about corridors***
  - ***Need to think about it more diffusely, particularly in working or dynamic landscapes. The matrix matters.***
  - ***Connectivity is a process***
- ***Redundancy is key***
  - ***Especially under changing land cover or climate***
- ***Circuit theory helps to:***
  - ***Quantify redundancy***
  - ***Prioritize pinch-points where connectivity might be lost sooner***
  - ***Identify restoration opportunities and explore change scenarios***



Resources

Software

Circuitscape: www.circuitscape.org
HexSim: www.hexsim.net
Connectivity Analysis Toolkit

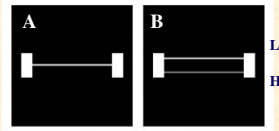
Articles

McRae et al. 2008 *Ecology*
Beier et al. 2008 *Conservation Biology*
Spear et al. 2010 *Molecular Ecology*

Planning efforts

- Southwest Carnivore Connectivity
- Multispecies Connectivity on the Colorado Plateau
- California Essential Habitat Connectivity Project: http://www.dfg.ca.gov/habcon/connectivity/
- This Winter: Washington Connected Landscapes Project!

Simple landscapes (1000x1000 cells)



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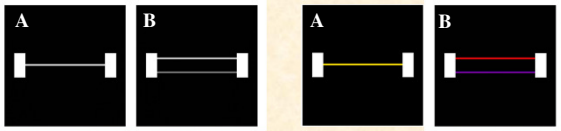
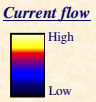
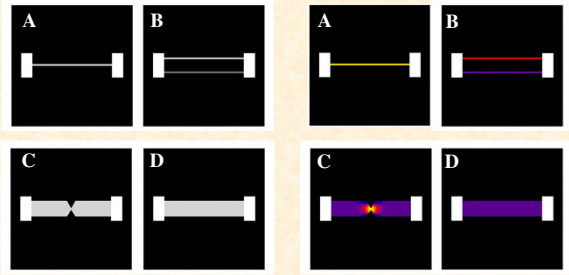
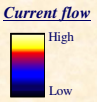


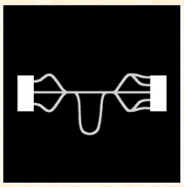


Simple landscapes (1000x1000 cells)

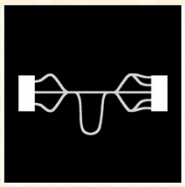




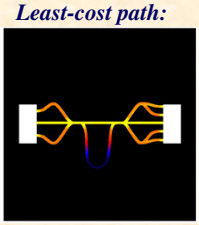
Circuit theory complements least-cost path: "braided stream" landscape

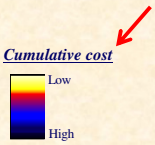


Circuit theory complements least-cost path: "braided stream" landscape

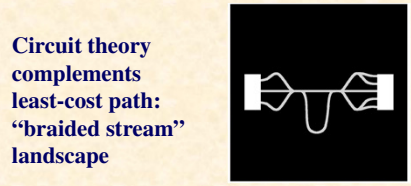


Least-cost path:

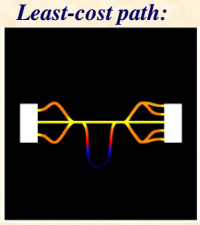




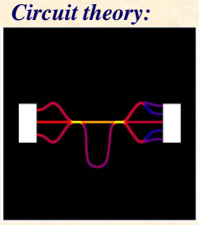
Circuit theory complements least-cost path: "braided stream" landscape



Least-cost path:



Circuit theory:



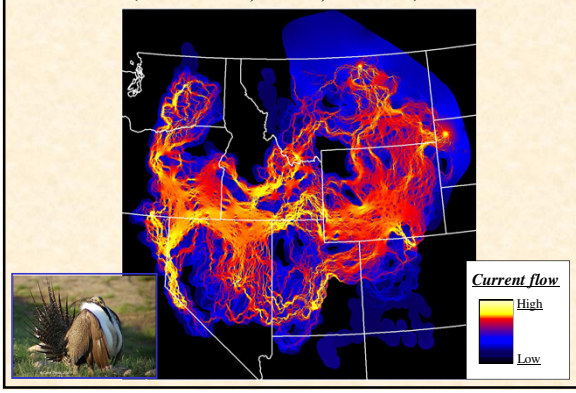
Current flow

High

Low

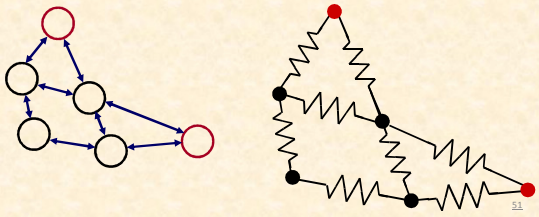
Greater Sage Grouse

(w/ C. Carroll, M. Leu, S. Hanser)



Application: predicting gene flow

Gene flow is increased by multiple connections and pathways



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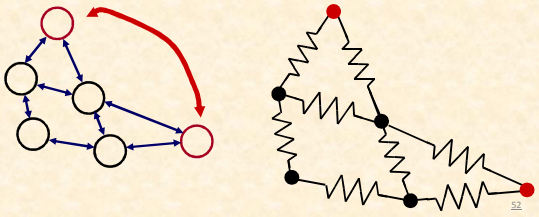
Application: predicting gene flow

Gene flow is increased by multiple connections and pathways

Gene flow: $\hat{M}$

Differentiation: F_{ST}



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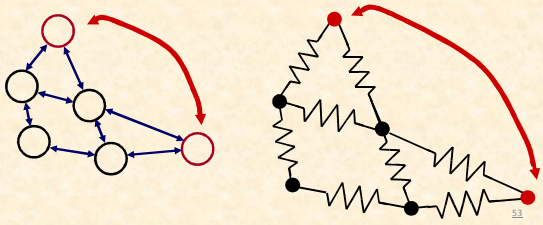
Application: predicting gene flow

Gene flow is increased by multiple connections and pathways

Gene flow: $\hat{M} \sim \hat{G}$

Differentiation: $F_{ST} \sim \hat{R}$



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